TABLE 1.—*Average number of days with hail, 1906–1915*—Continued.

South Atlantic States.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
North Carolina.													
Raleigh	0	0.2	0.1	0.1	0.2	0	0	0.1	0	0	0.1	0.1	0.9
Asheville	0	0.1	0.1	0	0.2	0.2	0.3	0.2	0	0	0	0	1.1
Charlotte	0.2	0.1	0.5	0	0	0	0.3	0	0	0	0.1	0.5	1.7
Wilmington	0	0	0.3	0.1	0	0.2	0	0	0	0	0	0	0.6
South Carolina.													
Columbia	0.1	0	0.2	0	0.2	0.3	0.1	0.2	0	0	0	0.1	1.2
Charleston	0	0.1	0	0.1	0.1	0	0	0.1	0.1	0	0	0	0.5
Georgia.													
Atlanta	0.1	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0	0.3	0.1	0.3	1.9
Augusta	0	0	0	0	0	0	0.1	0	0	0	0	0	0.1
Macon	0	0	0.2	0.1	0.3	0	0.3	0	0.1	0	0	0	1.0
Savannah	0	0	0	0	0.5	0.1	0	0	0	0	0	0	0.6

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LIGHTNING AND FOREST FIRES IN CALIFORNIA.

By ANDREW H. PALMER, Observer.

[Dated: U. S. Weather Bureau office, San Francisco, Cal., July 14, 1916.]

The inauguration of the fire-weather warning service as a part of the work of the U. S. Weather Bureau has opened another interesting field for investigation in meteorology.[1] New problems have presented themselves for solution. The difficulties encountered to date have been largely the result of a lack of data, the absence of normals, and the want of precedent. Though forest fires doubtless occurred long before man appeared on the earth, a systematic record as to their causes extends over comparatively few years. In the United States the matter was not given serious attention until 1880, when a table of forest-fire statistics was prepared as a part of the Tenth Census. The investigation of the relation of weather to forest fires is of even more recent date, while the fire-weather warning service was inaugurated in the Pacific Coast States in 1913 on the recommendation of District Forecaster E. A. Beals.

With reference to their origin, forest fires may be divided into two groups, those caused by man and those caused by nature. While those caused by man are the larger of the two groups, it is not the purpose of this paper to discuss them in detail. Those caused by nature may be subdivided into three groups, (1) those caused by "spontaneous" combustion, (2) those caused by volcanic eruptions, and (3) those caused by lightning.

"Spontaneous" combustion is a direct cause of forest fires only in rare instances, and as an observed source there are few cases on record. However, of the many forest fires of unknown origin it is believed that some, at least, were thus produced. The exudation of oils and other mineral matter from the ground, or the close packing of damp leaves and grass on the forest floor may at times produce chemical reactions which might result in combustion. Forest fires caused by volcanic eruptions had not been recognized in the United States until May 19, 1915, when an eruption of Lassen Peak in northeastern California was accompanied by a blast of superheated gases which kindled two forest fires in that vicinity.[2] As natural causes of forest fires spontaneous combustion and volcanic eruptions must therefore be considered rare in the United States. The third natural cause, lightning, and its relation to forest fires, is the subject of this discussion.

LIGHTNING AND FOREST FIRES IN THE UNITED STATES.

On the national forests of the United States during the five-year period 1911–1915, inclusive, fires were caused as follows: Railroads, 14.4 per cent; campers, 15.6 per cent; brush burning, 7.9 per cent; lumbering, 1.8 per cent; lightning, 29.5 per cent; incendiary, 8.7 per cent; miscellaneous, 5.2 per cent; and unknown, 16.8 per cent. Lightning is a more important factor in causing forest fires than it is in causing fires in cities, the proportion being in the ratio of 7 to 1.

The relation of lightning to forest fires in the United States was studied in 1912 by Mr. Fred G. Plummer, of the United States Forest Service.[3] The more important conclusions reached by Mr. Plummer may be briefly summarized as follows:

Trees are the objects most often struck by lightning, because: (*a*) They are the most numerous of all objects; (*b*) as a part of the ground, they extend upward and shorten the distance to a cloud; (*c*) their spreading branches in the air and spreading roots in the ground present the ideal form for conducting an electrical discharge to the earth. Any kind of tree is likely to be struck by lightning. The greatest number struck in any locality will be the dominant species. The likelihood of a tree being struck by lightning is increased: (*a*) If it is taller than surrounding trees; (*b*) if it is isolated; (*c*) if it is on high ground; (*d*) if it is well (deeply) rooted; (*e*) if it is the best conductor at the moment of the flash; that is, if temporary conditions, such as being wet by rain, transform it for the time from a poor conductor to a good one. Lightning may bring about a forest fire by igniting the tree itself or the humus at its base. Many forest fires caused by lightning probably start in the humus. Other things being equal, trees growing in different soils differ slightly in susceptibility to lightning stroke. One study gave these results: Loam, 23 per cent; sand, 18 per cent; clay, 17 per cent; and others, 42 per cent. Zones of marked hazard from lightning—due partly to soil variations, partly to mineral deposits, and partly to altitude—are recognized throughout the West. The conductivity of wood is governed by its moisture content and its temperature. Electricity traverses wood more easily in the longitudinal direction of its fibers than across them. About 2 per cent of trees struck by lightning are ignited. While trees do not differ greatly as to their susceptibility to lightning, they do differ greatly as to inflammability.

LIGHTNING AND FOREST FIRES IN CALIFORNIA.

In California there are 18 national forests in which are included a total area of 19,575,000 acres. Not all of this land is timbered, but there are about 17,400,000 acres of standing timber in the State. These 18 national forests, which are separate and distinct from the national parks, are shown in outline in figure 1. As California is a large State containing 5 per cent of the total area of the country, and as it has within its borders a great variety of topography, soil, and climate, its trees include 125 of the 500 to 600 species growing in the United States. An

[1] Concerning the fire-weather warning service see this REVIEW, March, 1916, 44: 133–139.—EDITOR.

[2] *Palmer, A. H.* An eruption of Lassen Peak. MONTHLY WEATHER REVIEW, October, 1916, 44: 571–572.

[3] *Plummer, Fred G.* Lightning in relation to forest fires. Washington, 1912. (Forest Service Bulletin 111.)

excellent opportunity is therefore offered for investigating the relation of weather and climate to forests, and the following remarks refer only to conditions which obtain in California.

The forests of California are confined mainly to the foothills and mountains. The level interior valleys and the barren deserts of the south are practically free from extensive forest growth. While soil is an important factor in determining forest distribution, climatic conditions are of even greater importance. Of these temperature and rainfall predominate. The desert regions of the south and the broad, fertile valleys of the San Joaquin and the Sacramento are too dry in the summer to allow vigorous forest development. By far the most important climatic control is precipitation, which varies from practically nothing to more than 100 inches per year in different parts of the State. On the average, precipitation increases with height above sealevel up to a certain level, above which it diminishes again. Up to the 6,500-foot level there is an average increase of about 0.9 inch in the annual rainfall with every 100-foot increase of height above sealevel, the rate of increase being particularly marked between the 3,000- and 4,000-foot levels. Beyond the 6,500-foot level the rate of increase becomes negative; that is, the mean annual precipitation decreases with height. The Sierra Nevada, while not perpetually snow covered, receives, during the winter months, the heaviest known snowfall in the United States. The State also has a distinct wet and a dry season, though the distinction is less marked in the mountains than elsewhere.

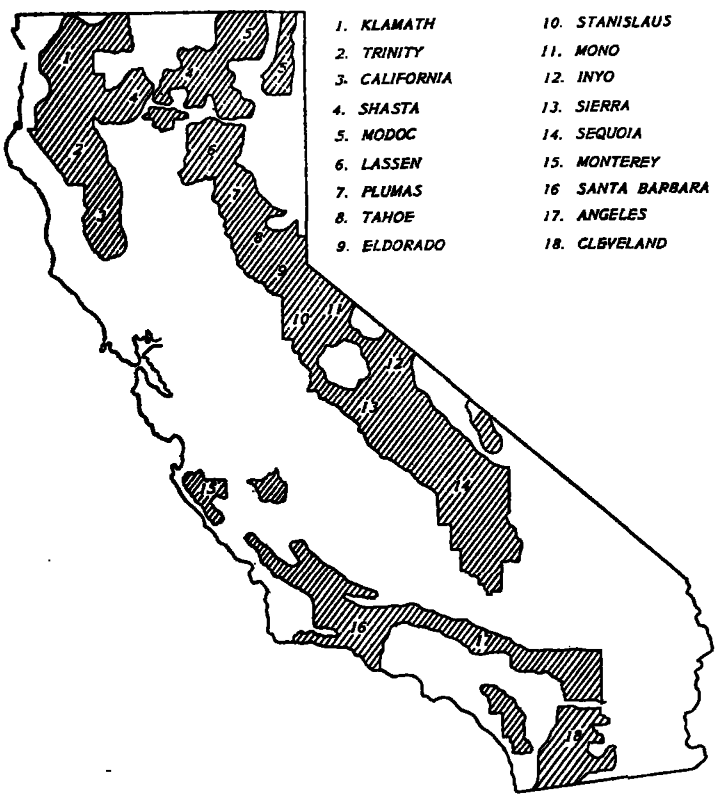

FIG. 1.—Outline map of California showing the locations and extents of its national forests.

Partly because of the increased precipitation and a more nearly uniform distribution throughout the year, and partly because of the absence of excessive heat during the ummer months, the forest regions coincide with the elevated portions of the State. Distance from the coast is also a factor which determines the distribution of certain trees. For example, the coast redwood, *Sequoia sempervirens*, one of the most typical of California trees, is found only within 30 miles of the coast. This is because it requires considerable moisture and a damp atmosphere throughout the year, and it can not endure severe temperature extremes. It is one of the few trees that can extract measurable precipitation from the fogs so common along the California coast in summer. A forest of this kind is dripping wet during a fog, the foliage acting as a condenser.

Weather when considered in its relation to the various causes of forest fires may be either a direct or an indirect influence. As an indirect factor it is more important than as a direct cause. This arises from a complex combination of conditions, which may be summarized briefly as follows: A drought is a prerequisite of a forest fire. High winds, partly because they accelerate evaporation, but principally because of their fanning effect are second only in importance to droughts as a contributory factor. Hot, northerly, desiccating winds, characteristic of the front portion of an anticyclone, are the most troublesome predisposing cause of forest fires in California. Moreover, the fine dry weather brings out the campers, increases the amount of railroad traffic, as well as the lumbering and brush burning, and thus further contributes to the fire hazard. As an indirect influence, therefore, the importance of the weather in its relation to forest fires is paramount.

It is as a direct cause of forest fires, however, that weather is here considered. Lightning is the sole direct agent through which weather operates to produce fires of this kind. Table 1 shows the fires, classified by causes, on the national forests of California for the eight-year period, 1908–1915, inclusive. Of the 7,789 fires observed during that period, 2,434, or at least 31 per cent, were due to lightning. Of the 6,353 fires in which the causes were determined, at least 38 per cent were due to lightning, but it is recognized that yet larger numbers might be nearer the truth since records are known to be incomplete for the present purpose. It was the most important single cause of forest fires. Both for the United States as a whole, with 29.5 per cent, and for California with 31 per cent lightning leads while railroads were fourth and fifth in importance, respectively. The difference is due partly to the relatively greater number of thunderstorms in the California forests, and partly to the relatively smaller amount of railroad traffic.

Of those forest fires whose causes were determined the percentage due to lightning each year was as follows: 1908, 37; 1909, 26; 1910, 32; 1911, 47; 1912, 33; 1913, 55; 1914, 36, and 1915, 25. The actual number of fires, as well as the number resulting from lightning, varied greatly from year to year, as is indicated in the table. However, lightning was the leading single cause in six of the eight years, careless campers in 1909 and 1915 alone causing more fires than lightning. If but 2 per cent of trees struck by lightning in California ignite, as Mr. Plummer states is true for the United States as a whole, it means that 121,700 trees were struck by lightning on the national forests of California during the eight years, or an average of 15,212 trees each year.[4] The importance

[4] The U. S. Forest Service states that even with the perfected fire-detection system some trees are doubtless struck by lightning which are never detected by the lookout men. Further it is the general practice not to include in fire reports fires due to lightning which do not require the presence of rangers or patrolmen. Rains often immediately follow lightning storms, thus making it unnecessary for the protective force to look after all fires caused by lightning.

From these considerations it appears that the reported cases furnish minimum figures rather than precise averages.—EDITOR.

FIG. 2.—An earlier stage in the development of a very severe thunderstorm either over or behind Mount Shasta, Cal. (Photo by C. A. Gilchrist.)

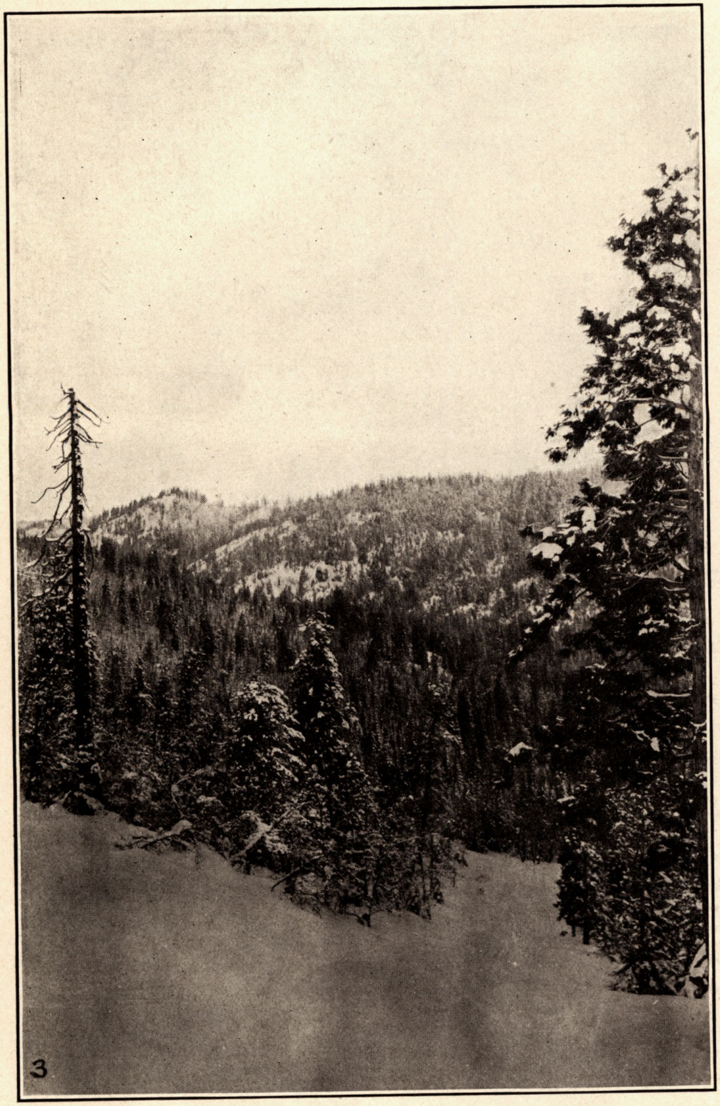

FIG. 3.—Mid-winter view of a forest near the summit of the Sierra in the region of greatest known snowfall in the United States. (Photo by A. H. Caine.)

FIG. 4.—In the heart of a mountain forest in January in the Sierra. This snow protects against winter fires and will become available as ground moisture during the long summer drought. (Photo by A. H. Caine.)

of lightning as a factor in the causes of forest fires is apparent from these figures.

TABLE 1.—*Fires in national forests in California, classified by causes.*

[Statistics furnished by U. S. Forest Service.]

Causes.	*1908	*1909	*1910	1911	1912	1913	1914	1915	Total.		Average number per year.
									No.	*P. ct.*	*No.*
Railroads......	12	22	11	24	93	64	70	25	321	4	40
Campers........	108	99	63	71	98	214	340	395	1,388	18	174
Brush burning.	17	37	29	38	42	78	45	75	361	5	45
Lumbering.....	......	14	11	15	29	46	69	71	255	3	32
Lightning......	158	84	110	282	206	804	480	310	2,434	31	304
Incendiary.....	13	17	59	92	71	133	212	301	898	12	112
Miscellaneous..	117	51	66	80	83	111	111	77	696	9	87
Unknown......	103	152	204	195	190	178	141	273	1,436	18	180
Total.....	*528	*476	*553	797	812	1,628	1,468	1,527	7,789	100	974

* Returns less complete for these years.

It is probable that few forest fires pass unobserved. During 1915 the U. S. Forest Service in California employed 85 lookout men and 555 rangers, patrolmen, and firemen. The lookout men were stationed on high peaks and reported fires to the district ranger by telephone or heliograph. In addition, private owners employed 80 patrolmen.

Lightning rarely occurs independently of a thunderstorm. Thunderstorms, however, are of various kinds. Those along the coast are limited almost entirely to the winter half-year, and are invariably of cyclonic origin, caused by the overrunning of a relatively warm stratum of air by one relatively colder. They come in ready-made from the ocean, are of short duration, and of feeble intensity, with few electric discharges in the form of lightning. But one thunderstorm occurs each year on the average at San Francisco. In the mountain regions, however, where most of the forests are situated, thunderstorms occur throughout the year, though they are most frequent during the summer months. They are often violent and long continued, and are accompanied by numerous lightning discharges. Under the strong insolation which California receives during the long summer days, local heating of the air results in vertical convection which produces cumulus clouds, a characteristic feature of the landscape during afternoon hours. Under favorable conditions, which include moderate or high humidity and calms or light winds, these cumulus clouds become overdeveloped and produce cumulo-nimbus, or thunderheads. The photograph shown in figure 2 was taken by Mr. C. A. Gilchrist and is here reproduced through his courtesy. It shows a stage in the formation of a thunderstorm over Mount Shasta. This particular storm subsequently attained great violence, and was accompanied by destructive lightning. As indicated in the foreground, the view was taken during the haying time of early summer, when snow was still abundant on Shasta. The summit of this mountain is 14,380 feet above sealevel and more than 2 miles above the floor of the valley shown in the foreground. It would thus appear that the cirrus cap at the top of the ascending column must have been fully 5 miles above the top of the mountain, or about 8 miles above sealevel.

During the summer months the weather of California is dominated by the great North Pacific HIGH. For this reason the surface winds are local in origin, while the upper air is almost stagnant, as far as horizontal currents are concerned. The amount of rain which accompanies these local thunderstorms varies greatly, though it is generally light. No relation is apparent between the amount of rain which falls during one of these storms and the number of lightning flashes. However, it has been observed that the deeper the storm; that is, the greater the height reached by the ascending current, the more frequent are the electrical discharges. When lightning strikes a forest tree the accompanying rainfall will often prevent ignition, thus accounting in part, at least, for the fact that 98 per cent of trees struck by lightning are not set on fire. Moreover, a rainfall of 0.25 inch will make it practically impossible for a fire to spread. Many thunderstorms, however, are accompanied by no measurable rainfall. Furthermore, when anticyclonic conditions are well developed the resulting surface winds are from the north or northeast, the direction of most dangerous "fire winds" in the State. Partly because of their excessive dryness, but principally because of their fanning effect, these winds are most dreaded by foresters while fighting a forest fire.

It might be inferred from the foregoing that lightning as a factor in causing forest fires, varies with different forests as well as with different years. That such is the case may be noted from Table 2, which shows the number of fires on the 18 national forests during the four years, 1912–1915, inclusive, and the number and percentage caused by lightning. It is noteworthy that the Santa Barbara Forest, the one nearest the coast, had the least number of lightning fires, and not a single fire caused by lightning in 1912 or in 1915, though 50 fires occurred during the former year and 147 fires during the latter year. On the other hand the Modoc Forest, the one farthest distant from the coast and well up in the mountains, had relatively the greatest number of lightning fires, 84.6 per cent of those in 1912 and 72.2 per cent of those in 1915 having been so caused. The great contrast is due principally to the difference in the frequency and in the nature of thunderstorms in the two forests, the one at a low altitude along the coast, the other at a great altitude in the interior.

Thunderstorms, like certain other elements of the weather, vary in number from year to year, and for this reason the number of lightning fires varies. As may be inferred from figures 3 and 4, which are winter photographs of California forests taken by Mr. A. H. Caine, thunderstorms which occur during that season rarely start forest fires. The humus and forest litter is then either snow covered or has been saturated by rains. In these mountain regions 85 per cent of all the precipitation received during the course of the year falls in the form of snow. Moreover, the violent thunderstorms originating from local surface heating are then infrequent. The great majority of forest fires in California occur during the months, July to September, inclusive. The winter snow is important in another respect. It is recognized that susceptibility to forest fires during the summer months depends not only upon the character of that season, but also upon the amount of snow which fell the preceding winter and the manner and rate of its disappearance upon melting. The importance of these considerations is apparent when the dryness of the forest floor is recognized as a factor. The average man, unacquainted with forest conditions, would marvel at the ease with which such an apparently green forest would ignite, even though the snow has but recently melted. Figure 5 is another photograph of Mount Shasta, showing a forest and lumber piles at its base. Sparks blowing from the smokestacks of sawmills like the one here shown were formerly a prolific source of forest and lumber-yard fires. The adoption of efficient spark screens has now largely eliminated that cause of fires.

TABLE 2.—*Fires in the national forests in California showing number and percentage caused by lightning during 1912–1915.*

[Statistics by U. S. Forest Service.]

Forest. [Cf. Fig. 1.]	1912			1913			1914			1915		
	Total number of fires.	Lightning fires.		Total number of fires.	Lightning fires.		Total number of fires.	Lightning fires.		Total number of fires.	Lightning fires.	
	No.	*No.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*No.*	*No.*	*P. ct.*
Angeles	72	2	3	130	27	21	136	4	3	116	7	6
California	20	5	25	76	35	46	48	6	12	24	1	4
Cleveland	41	0	0	72	43	60	78	14	18	37	1	3
Eldorado	22	2	9	74	10	14	46	15	33	74	5	7
Inyo	3	1	33	5	3	60	4	3	75	3	0	0
Klamath	85	32	38	126	85	67	163	103	64	219	37	17
Lassen	65	40	62	77	48	62	95	60	63	92	34	37
Modoc	26	22	85	49	36	73	51	35	69	72	52	72
Mono	4	2	50	6	6	100	5	1	20	15	5	33
Monterey	5	0	0	8	0	0	2	0	0	15	2	13
Plumas	96	30	31	156	84	54	149	32	22	108	27	25
Santa Barbara	50	0	0	63	5	8	57	3	5	147	0	0
Sequoia	80	3	4	127	91	72	81	47	58	36	10	28
Shasta	56	29	52	129	62	48	133	34	26	196	77	39
Sierra	67	1	1	172	77	45	88	30	34	37	4	11
Stanislaus	23	3	13	101	49	48	58	12	21	30	4	13
Tahoe	60	5	8	120	45	38	223	53	24	163	17	10
Trinity	37	29	78	137	98	72	53	28	53	143	27	19
Total	812	206	25	1,628	804	49	1,468	480	33	1,527	310	20

Total number of fires during 4-year period	5,435
Number of lightning fires during same period	1,800
Average annual number of lightning fires	450
Percentage of lightning fires to total number	33

It should be borne in mind that all forest fires started as small fires. When lightning strikes a tree it may ignite the tree or the débris and undergrowth beneath, the fire later spreading if conditions are favorable. Of the three kinds of fires recognized by the Forest Service, all may be caused by lightning. These three kinds are (1) ground fires, which smolder indefinitely in the ground, consuming humus, duff, and roots of trees; (2) surface fires, which spread over the surface of the forest floor, fed by undergrowth and débris; and (3) crown fires, which consume the entire forest cover.

As in other States, California has zones peculiarly susceptible to lightning; zones which are perhaps independent of possible topographic influences. Every ranger and lookout recognizes certain well-defined belts where lightning strikes most frequently. As a result, many local traditions have arisen and most of these are based on accurate observations.

According to Mr. Plummer[5] scars traceable in the annual rings of the famous Big Trees of California suggest that great forest fires occurred about the years 245, 1441, 1580, and 1797 A. D. It is known that the American Indians have occasionally set fire to forests in order to clear the land for agriculture, to drive game, or to impede the progress of an enemy, but it is more likely that these great fires were kindled by lightning. These trees also refute the popular superstition that lightning never strikes twice in the same place. Certain trees are known to have been struck eight times, with no other apparent effect than a dwarfed growth.

CONCLUSION.

The importance of lightning as a cause of forest fires may be judged from the foregoing statements. Being of natural origin, lightning is one of the factors which can never be eliminated. However, the situation is not hopeless. The main hope lies in the anticipation of fires and the making available of facilities to subdue them when they occur. The fire-weather warning service gives hope of reward. Thunderstorms with their destructive lightning form simply one of the elements which must be considered. In this, as in other branches, the dominant need is for more field work in order to secure more complete data with reference to each individual forest. As this information is secured further advance may be expected of meteorology in general, and of fire-weather forecasting in particular.

[5] *Plummer, Fred G.* Forest fires. Washington, 1912. (Forest Service Bulletin 117.)

551.578.46 (793)

THE DENSITY OF SNOW.

By Prof. ALFRED J. HENRY.

WITH A NOTE ON THE DISAPPEARANCE AND SETTLING OF SNOW IN 1915–16 NEAR RENO, NEV.

By HENRY F. ALCIATORE, Meteorologist.

CONTENTS.

Definitions.—The generic term density is defined as *mass divided by volume*, or mass per unit volume. The literature of the density of snow frequently contains such terms as "relative" density, "specific" density, and "specific gravity," all of which are comprehended in the simple term density. Relative density as ordinarily defined is the ratio of the mass of any volume of the substance to an equal volume of a standard substance. Water at a specified temperature and pressure is generally taken as the standard substance for solids and liquids and hydrogen for gases. The "specific" density of a substance is merely another way of expressing the specific gravity of the substance. The terms "specific density" and "specific gravity" are interchangeable.

In this paper the term "density" is considered as equivalent to either "relative" density, "specific" density, or "specific gravity" of snow, and it will be expressed numerically as a three-place decimal. Thus, 0.100 (read one hundred thousandths,) that is, snow having a density of 1 to 10, or water equivalent of 1 inch in 10. By disposing of the third decimal, the density values may be thought of as percentages.

The rule followed by the Weather Bureau in disposing of decimals is to increase the last significant figure by